

## 1

# Soil Diversity in the Tropics: Implications for Agricultural Development

H. Eswaran, J. Kimble, and T. Cook

USDA-SCS  
Washington, DC

F. H. Beinroth

University of Puerto Rico  
Mayaguez, Puerto Rico

The term *laterite* readily comes to mind when the subject of tropical soils is raised. Yet, there is great scope for soil variability in the tropics. The soils that have been referred to as a laterite are, in fact, but of minor extent there. Understanding this diversity and the distribution, characteristics, and processes of the soils of the tropics is obviously of pivotal importance to their wise agricultural development.

Historically, the nature and properties of soils have been an important determinant in cultural and economic development. Many ancient civilizations evolved in the fertile alluvial soils associated with the deltas at the margins of oceans and the floodplains of navigable rivers that were also the avenues for trade, commerce, and communication and thus brought about the emergence of great cities of the past and present. In other areas, such as tropical uplands, the low inherent soil fertility led to farming systems known as *shifting cultivation* or *slash-and-burn agriculture*.

As farmers elsewhere, the farmers of the tropics are keenly aware of soil diversity. This is evidenced by the fact that the "primitive" agriculture of every country is located on the soils with the least constraints. Thus, the more fertile Inceptisols, although they often occur on steep slopes, are preferred to the infertile Oxisols on adjacent plateaus. And the native Indians in the Andean countries preferred volcanic ash soils in the cool uplands to the soils in the hot, humid, and disease-prone Amazon basin.

Since the 1970s, however, population pressures and scarcity of good soils have forced agriculture to expand into hilly, or mountainous, or swamp areas. In parts of East Africa, wildlife is threatened by the encroachment of agriculture into wildlife habitats. In the humid tropics, systematic clearing of the

forests for agriculture and other purposes has purportedly contributed to the greenhouse effect resulting in global warming. In the semi-arid tropics, uncontrolled irrigation has begun to salinize large areas of land, completely changing the ecosystem.

Two questions arise: (1) Do we know enough about soil diversity? and (2) How do we manage soil diversity so that we have rational land use for competing purposes? These two questions are examined in the context of this publication.

## ASSESSING SOIL DIVERSITY

### Defining Tropical Soils

Tropical soils may be defined as all those soils that occur in the geographic tropics, that is, in that region of the earth lying between the Tropic of Cancer and the Tropic of Capricorn, also known as the Torrid Zone. The adjective tropical, however, is commonly associated with hot and sultry conditions. Consequently, many think of tropical soils as the soils of the hot and humid tropics only, exemplified by deep, red, and highly weathered soils.

We consider tropical soils to be those that have an "iso" soil temperature regime and lie between the tropics of Cancer and Capricorn. As defined in *Soil Taxonomy* (Soil Survey Staff, 1975), the U.S. system of soil taxonomy, such regimes denote a difference between mean summer and mean winter soil temperatures of 5°C or less. The implication of an iso-temperature regime, in areas with a mean annual soil temperature > 5°C, is that temperature is not a constraint for most year-round agricultural uses. Iso soil temperatures regimes are almost exclusively confined to the intertropical regions and thus may be considered a soil property that sets the soils of the tropics apart from all other soils. As the tropics comprise approximately 40% of the land surface of the earth, more than one-third of the soils of the world are tropical soils.

### Causes of Soil Diversity in the Tropics

Rationalizing soil diversity in terms of the environmental soil-forming factors first postulated by Dokuchaev about 100 yr ago continues to be the unifying philosophy in pedology. In the context of this perspective, the great diversity of soils in the tropics is an inevitable consequence of the enormous diversity of ecosystems found in the intertropical areas. Both the driest and wettest spot on earth are in the tropics, namely in the Atacama Desert, where only sporadic traces of rainfall occur, and on Mt. Waialeala in Hawaii where more than 11 700 mm have been recorded. Mean annual temperatures vary from around 30°C at the low elevations to below 0°C on the snowcapped mountains of South America and East Africa. Covariant with this climatic variability, there occur a multitude of ecosystems from deserts to rain forests.

As there was no Pleistocene glaciation in the tropics, many landscapes predate the Quarternary and remnants of peneplains as old as mid-Tertiary, about 20 million yr, are not uncommon. Yet they may occur in juxtaposition with surfaces of recent age. There is also much scope for variation in soil parent material since, with the notable exception of Pleistocene glacial formations such as till and loess, all of the rocks of the temperate zone are also found in the tropics. Moreover, as some soil-forming conditions are unique to the tropics, they have produced soils that can only be found there, (e.g., the Oxisols on ancient geomorphic surfaces).

Some of the oldest geomorphic surfaces are also to be found in the intertropical areas. Examples are the Amazon Shield, the Tertiary surfaces of Africa and southern India. These surfaces have been subject to uplift and tilting with concomitant peneplanation as the most important geomorphic process. As a result, geomorphology is and has been an important control of soil formation in the soils on the older surfaces. Lithological discontinuities marked by stone lines or particle-size differences, are characteristic features of these soils and contribute to the diversity. On the mid- and end-Tertiary surfaces in Africa, the soils and their parent material may have little or no relationship to the underlying rock. In these reworked soils or "sols remaniés," as described in the French literature, the present-day soil is formed on the pedisegment and has little or no relationship to the underlying weathering rock or the rock itself.

In view of the immense environmental diversity encountered in the tropics, often over short distances, the complexity and variability of the resultant soils patterns should come as no surprise. The small island of Puerto Rico may serve as an example: in an area of <9000 km<sup>2</sup>, soils representing 10 of the 11 orders currently recognized in *Soil Taxonomy* have been identified.

### Cartography and Soil Diversity

Soil diversity is a function of the scale of observation as well as land use. The classes in *Soil Taxonomy* (Soil Survey Staff, 1975) provide for expression of this diversity. Although there is no reliable information on the number of classes occurring in the tropics, particularly at the lower categorical levels, an estimate is given in Table 1-1.

Table 1-1. Estimates of number of soils in each category of the U.S. system of soil taxonomy in the tropics.

Taxonomic level	Estimate of number of soils
Order	11
Suborder	45
Great group	200
Subgroup	1 250
Family	1 000 000
Series	5 000 000
Phases of series	10 000 000

Soil diversity is a function of scale of observation and perhaps a reference level is the minimum decision area (MDA) which is the size of an average small-holder farm in the tropics. For practical purposes this is 1 ha which, when equated to the minimum size of delineation (MSD) on a soil map, requires detailed maps at scales of at least 1:10 000. Variability within MDAs affect farmer performance, and variations between MDAs, the ability to transfer technology and enhance farmer productivity. The number of classes



Fig. 1-1. An example of a detailed soil map of an experimental station (Uganda) (Yost & Eswaran, 1991).

indicate the number of identifiable or mappable entities. Maps at scales of about 1:15 000 (Fig. 1-1) usually depict phases of series but maps at more detailed scales would show greater diversity. Table 1-2 shows the relationship between map scales, minimum size delineation and minimum decision area with respect to scale.

Diversity is also a function of the landscape on which the soils occur. Alluvial terraces and old peneplains tend to be more homogeneous with respect to patterns of soils than steeplands or dissected landscapes. Diversity is also in the eyes of the beholder; some tend to see more variability than others. Soil maps are made for specific objectives and mappers attempt to seek map purity or reduce the variability within map units. Map unit purity and soil variability are obviously objective specific; an area may be considered uniform for rangeland but have considerable variability for cropland.

Many misconceptions regarding the kinds of soils in the tropics arose due to a lack of appreciation of this diversity. This was due to the fact that, until recently, there were only very broad reconnaissance soils maps of the tropical regions. Much of the information about soils in the tropics was accumulated during the period after World War II and came initially from ad hoc observations of a few individuals. The 1:5 000 000 FAO Soil Map of the World aided considerably to erase some of the misconceptions. Though these maps were published in the 1970s, many of the misconceptions have still been carried through. Part of the reason is that apart from soil scientists, many still do not appreciate the terminology introduced in the FAO legend of the Soil Map of the World or in *Soil Taxonomy*. In addition, the amount of information available, as shown by the reliability map for the sheets covering Africa in Fig. 1-2, at the time the FAO map was compiled was inadequate to make a reliable assessment of the soil resources of the continent. Yet even today, this is the best information we have for many parts of Africa. Some countries such as Zambia, Kenya, and Botswana have more recent maps, including maps at larger scales, which differ significantly from the FAO maps. This is, of course, not a criticism of the FAO effort but merely emphasizes the need for more detailed and accurate information

Table 1-2. Map scales, minimum size delineations (MSD) and minimum decision areas (MDA). MSD is the smallest area in which a symbol can be printed on a map. MDA is the smallest area on map from which reliable information can be derived for interpretations. Generally MDA is (4 × MSD).

Map scale	Minimum size delineation		Minimum decision area
	Acres	ha	ha
1:500	0.0025	0.001	0.004
1:2 000	0.040	0.016	0.064
1:5 000	0.25	0.10	0.40
1:10 000	1.00	0.41	1.64
1:20 000	4.00	1.6	6.4
1:100 000	100	40.5	162
1:250 000	623	252	1006
1:1 000 000	10 000	4 000	16 000
1:5 000 000	249 000	101 000	404 000

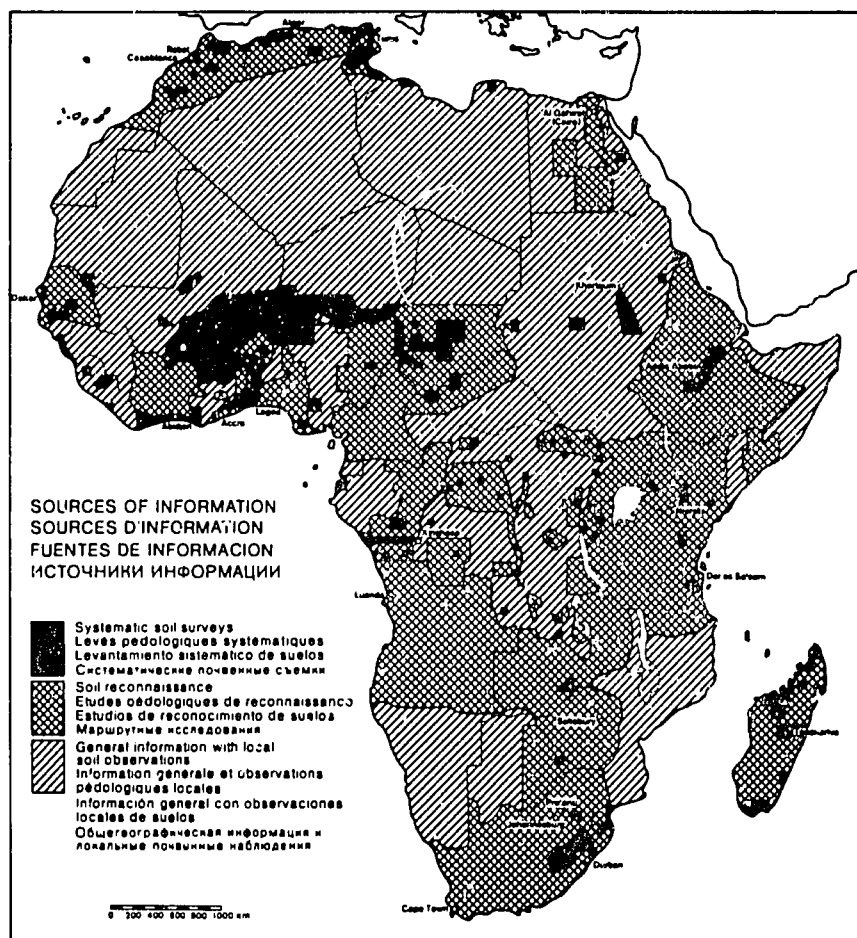


Fig. 1-2. Map showing reliability of FAO's soil map of the world.

that is recognized by all. Nevertheless, it must be realized that basing evaluations by necessity on the generalized world soil map can result in misconceptions and errors.

## NOMENCLATURE

Soils nomenclature, particularly as employed by the different kinds of classification systems in existence around the world, has contributed to some of the myths and misconceptions and, in some instances, even confused the issue. Classes in taxonomic systems and map units have observable and measurable properties that fall within class limits that are defined. The same class may show considerable variations in other properties that are not class defining. For some purposes, this variability may be too broad and therefore single property or thematic maps are produced. Good examples are  $\text{NO}_3$  status

or contents of nutrient elements in soils that are useful information for fertility specialists but are not available from soil survey reports.

Some of the older classification systems, many of which have yet to be modified or improved, employ general and common terms for the classes and differentiate were not strictly defined with respect to class limits. Classification was generally a consensus of opinion (or even the opinion of the leaders) rather than a scientific exercise. This bred a profusion of terms, which though very broad in scope, had good appeal among laypeople. For these reasons, when the U.S. system of soil taxonomy was being developed, a decision was made not to use the old and commonly folkloristic names.

The most notorious of such terms is *lateritic soils* the application of which ranged from any soil of the tropics to the unique feature of a true laterite. Even the term *laterite* had and has a range of meanings and consequently is not employed in the U.S. system of soil taxonomy. However, it still is a popular term among other users of soils, particularly engineers, and thus continues to be a problem today. Names in the U.S. system of soil taxonomy are technical and complicated to the layperson and so many agronomists and plant breeders do not understand them. The situation is worse with economists and sociologists who generally are the decision makers in national or international development programs.

Confusion caused by nomenclature dates back to the 10th century or earlier. The following (cited by Dudal & Eswaran, 1988) illustrates the debate on black soils:

Democritus state that the best natured soil is the one that takes in rainwater easily, that does not become sticky at the surface, and that does not crack when the rains have ceased. Soils which do not crust as a result of heat are good natured. As a result, says IBN JEDJADJ, to be a good soil it should be neither sticky nor hard. Some have told me, he adds, 'How can the wise DEMOCRITES criticize soils that crack since we see that the soils of the territory of Carmona, which show these features produce higher yields of wheat than those on soils anywhere else?' So, I say that this soil can be depreciated only in comparison with other soils which are of prime quality according to the principles established above. On the other hand, one should not rank the soils that crack among those of first quality just because they produce good wheat. Since a major part of the seeds and plants entrusted to these soils (VERTISOLS) do not do well, how could we not give preference to other soils. The black soils with a not too dense texture, which resemble old and well decomposed manure and in which all kinds of seeds and plants succeed (MOLLISOLS), should be rated first class on account of their superior quality.

Ibn-Al-Awam  
(ca. 10th century)

## MYTHS AND REALITY

Myths arise out of misuse of terms, ignorance, and, in the context of developing countries, a desire to achieve the maximum with minimum inputs.

## Soil Formation in the Tropics

Knowledge about pedogenesis in the tropics is still incomplete and probably at the relative state where it was 50 yr ago for the temperate areas. This is, of course, related to the difference in the magnitude of pedologic research in the two regions. While the ratio of intertropical to nontropical land areas is about 1:3, that of soil scientists working in the two regions is probably 1:1000.

Pedologists have been accused of looking at the soils of the tropics through "temperate" eyes and studying them in the context of this perspective; the underlying implication being that soil formation in the tropics is somehow very different from soil formation in the higher latitudes. Statements to this effect are only partially correct, however, since the basic processes and reactions of soil formation are the same everywhere. Pedogenetic processes such as lessivage, pedoturbation, eluviation and illuviation, decalcification, and mineralization are universal in nature. Reactions such as hydrolysis, oxidation, and reduction have no geographic boundaries.

Yet, while there is no real difference in the kind of processes operating in the tropics, there may be significant differences in degree. In part of the tropics, the combination of high temperatures, copious amounts of rainfall, and geomorphic stability over millions of years have allowed the pedogenic processes to produce extreme manifestations of soil formation, namely the Oxisols. Figure 1-3, modified from Birkeland (1984) illustrates the differential rates of soil formation in three Orders of soils. The conditions conducive to the formation of such soils are far from ubiquitous, however, and consequently Oxisols account for only about 15% of the intertropical land area. Nevertheless, because Oxisols are unique to this area, the tropics are the only region where all of the 11 soil orders of the U.S. system of soil taxonomy occur.

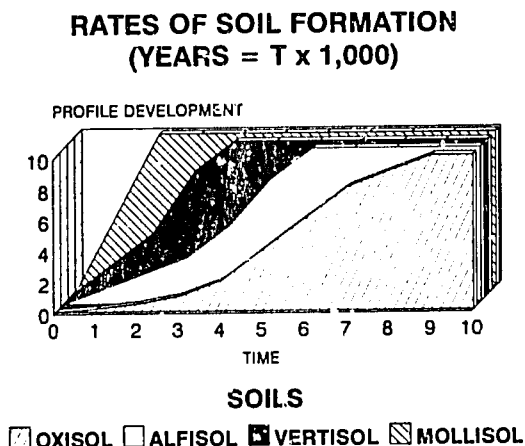


Fig. 1-3. Estimates of time required for formation of different soils. (Modified from Birkeland, 1984.)

### Considerations on Soil Formation

Basic differences in soil-forming conditions are related to geology, paleoclimate, geomorphology, and current factors of soil formation. The tropics were free of glaciation and its rejuvenation effects but subject to the pluvial and interpluvial effects. In the tropics, there are soils on old rocks on old landscapes where uplift, erosion, and peneplanation are the main controls of soil formation and these have operated under a high and relatively constant ambient temperature. Soil-geomorphic relationships have a different meaning in the tropics as these must be viewed in the context of paleoclimatic conditions for which there have been few studies. Stone-lines and lithological discontinuities are the norm in the tropics but few studies have focused on these. Many times they are ignored. Horizons of translocated clay accumulation may occur at the top, in the middle, or at the base of the soil and each has a special significance. If an argillic horizon is defined purely on a clay increase, which is the modal situation on the loess of the Midwest, an important genetic property of the tropical soils is lost.

Bioturbation is an important process but on the old landscape of the tropics, it has been in operation for eons. It may have destroyed the evidence of clay translocation (cutans); it has contributed to sorting of particles in the soil; it has modified some features or contributed to the specific morphology of others such as vesicular laterites. As little attention is placed on this aspect of soil formation in the tropics, little is known about these processes.

Recognition and understanding of the processes are important to appreciate the diversity of soils that occur in this environment.

## PROPERTIES OF TROPICAL SOILS

### Implications for Fertility of Tropical Soils

It is ironic, but agronomists and soil-fertility specialists are often among those who are most ignorant of soil diversity in the tropics. Since the initiation of soil-fertility research decades ago, the same kinds of experiments have been conducted and repeated all over the world with no end in sight. The N-P-K trials keep an agronomist employed, which may be the reason why the experiments never end. In practically every country of the tropics, there is one fertilizer policy for the whole country that may date back to the independence of the country or dictated by a fertilizer supplier. Performance appraisal of the institution is based on the number of soil samples analyzed per year. If all the analyses over the last 50 yr were tabulated, it would not be surprising if essentially every arable soil in the country has been analyzed; yet the process continues.

What many agronomists appear to ignore is that soils are different. Each one or each group of them, requires different management techniques. However, once response patterns have been established and understood, they

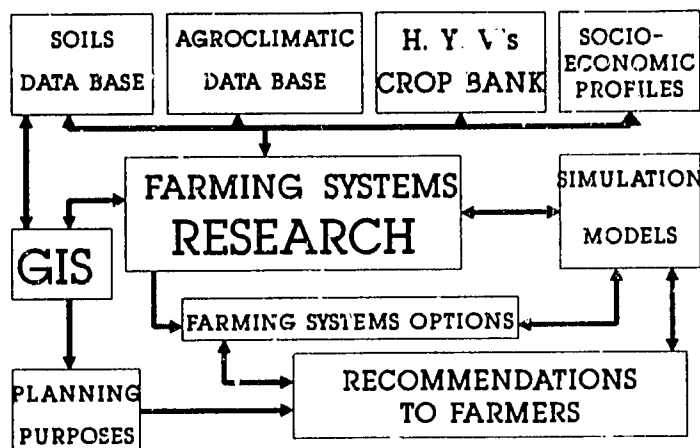


Fig. 1-4. A decision support systems approach to sustainable farming systems research.

can serve to develop models for future management and technology transfer. Figure 1-4 (from Virmani & Eswaran, 1991), shows how databases, particularly soil database, are crucial components in farming systems research and development.

Appreciation of soil diversity in the tropics and aligning management technology to match the specific soil requirements results in considerable savings in foreign exchange, apart from increasing the productivity of agricultural systems.

## SOIL DIVERSITY AND SUSTAINABLE AGRICULTURE

What is the soil component in sustainable agriculture? Little is known and no emphasis is given to this important question. International donors such as the U.S. Agency for International Development (AID) are gearing up to meet the challenges of sustainable agriculture but their approach is generally socioeconomic, improving performance, or reducing erosion. They, however, do not seem to appreciate that no one technology will suffice for all situations and that the basic reason is the variability in soil properties. Figure 1-5 (from Eswaran & Virmani, 1990) attempts to illustrate the period a soil would be sustainable under low-input agriculture—the basic tenets of sustainable agriculture. Sustainable agriculture requires not only a knowledge of the resource base but also their attributes and their distribution.

Much of current research activities are confined to experimental stations. Recently, there has been a shift to include farmer's fields. In most developing countries, neither the experimental fields nor the farms are adequately characterized. This raises the question of the utility of such research where the results cannot be transferred to another locality. Apart from this aspect of agronomic research in developing countries, from the point of view of sustainable agriculture, a major shift in research focus is needed. A farm

### RELATIVE RATES OF SOIL DEGRADATION (TIME = X 10 YEARS)

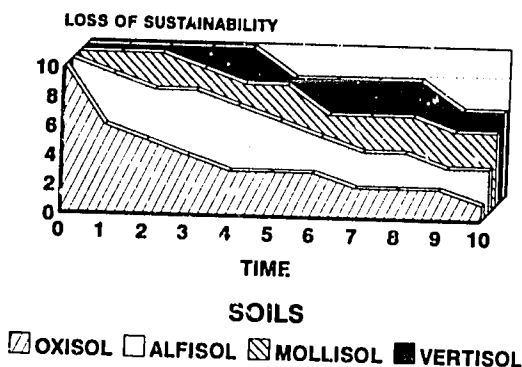


Fig. 1-5. Schematic diagram illustrating period during which low input agriculture is sustainable on different soils.

is a component of a watershed or catchment and from a sustainable agriculture point of view, it is equally important to evaluate other components or segments of the watershed. This calls for a holistic approach or a system-based approach and requires major innovations in research management.

Sustainability also requires evaluations over a time frame that may be of the order of a decade or more. Most donor-funded projects in developing countries do not exceed five and rarely 10 yr. Local staff are few and soon are promoted to other positions. As a result, the life of many field experiments may not be more than 2 or 3 yr. This period is insufficient, particularly in the semiarid tropics, where rainfall can have a coefficient of variation (CV) as high as 30%. There is always the uncertainty if the good responses to the treatments were coincidental, due to the prevailing good weather or if it was a real response to the treatment.

The International Agricultural Research Centers have developed all kind of technologies for their mandated crops. Their general approach is to develop and test a technology under different environments (outreach programs) rather than determining the environments and designing the technologies suited to these situations. This simpler approach is adopted largely because there is insufficient detailed soils information in many of the tropical countries. So should not the donors such as AID be also investing funds to enhance the knowledge of soils of the tropics in their quest for sustainable agriculture?

### DEVELOPMENT STRATEGIES

The current knowledge of the soils of the tropics clearly indicates that there is considerable diversity of the soils and the immediate need is to manage this diversity in the context of sustainable agriculture. The approaches are many but if executed in a coordinated manner, the goal is tenable. Some of the prerequisites are discussed below.

## **Documenting Diversity**

As a priority activity, detailed soil surveys must be initiated in all the countries and preferably according to the norms and quality control mechanisms of the Soil Conservation Service of USDA. A trip through the tropical world is an adventure where one can see relicts of soil surveys conducted by fly-by-night consulting companies, expert expatriates many of whom encountered the tropics for the first time.

The U.S. system of soil taxonomy is the only soil classification system designed and improved to meet the conditions of the tropics and which is designed for the explicit purpose of making and interpreting soil surveys. If U.S. funds are involved, it should be mandatory that the U.S. system of soil taxonomy be used and that standards of the SCS of the USDA be adhered to. Many foreign donors are still involved in making soil maps and many decisions, including farm-level decisions, are made on the basis of such maps. There are sufficient general maps of all countries and U.S. development activities should not contribute to more general maps.

## **Targeting Farming Systems and Conservation Measures**

There is increasing awareness of soil degradation today and the concept of sustainable agriculture calls for minimizing degradation. However, the concept of degradation is still subjective and a condition that constitutes degradation on one kind of land may be considered normal elsewhere. In addition, there is still considerable difficulty in differentiating natural degradation from anthropogenic degradation. Some erosion will always occur on steep lands and in the tropics. No catchment can contain all the monsoon rains so some erosion is bound to occur. With no comprehensive base line data for distinguishing the two kinds of degradation in the tropics, decision makers have difficulty in making policy decisions. In fact, Little and Harowitz (1987) report that land use studies of a given area, each purporting to be scientific, can come to widely divergent conclusions about what needs to be done.

A good detailed soil map is the tool for targeting soil conservation measures, recommending farming systems, and for most other uses of soil surveys. Since detailed soil surveys are unavailable in many tropical countries, soil survey interpretation is not appreciated. Instead, land evaluation is in vogue and urged upon by many international organizations, many national policy decisions are being made in the absence of base line data. Land evaluation is a good tool but becomes a meaningless exercise in the absence of reliable and detailed resource information. The fantasy in the developing countries and subscribed to by reputable international organizations and donors, is that land evaluation can be conducted with minimal resource information.

There is a need for a change in the philosophy of farming systems research. Farming systems must recognize soil diversity and must be designed to meet the constraints imposed by this diversity. Matching farming systems

to soil properties should become one of the objectives of the research component of sustainable agriculture.

### **Perceptions of National Decision Makers**

In most developing countries, perception of the decision makers is largely influenced by donors and activities of international agricultural organizations. The focus of international research organizations and donors, in the recent past was on improved cultivars—the short cut to increased production. Now with the emphasis on sustainable agriculture, and on productivity rather than on production, there should be a change in some of these priorities and as indicated previously, resource evaluation and conservation need greater thrust. However, this will not happen if donors and the International Agricultural Research Centers (IARCs) do not subscribe to this idea.

### **Application of Modern Technology**

The sparsely populated areas in the less developed countries (LDCs) of the tropics constitute most of the few remaining development frontiers. Growing environmental concerns make it imperative that the inevitable agricultural development of many of these areas in the near future must be guided by rational land use planning. Knowledge about soil is obviously a decisive factor in these considerations and traditionally soil surveys have been made and used to provide the soil information needed for land evaluation. While conventional soil inventories continue to be the backbone of land evaluation, methodologies are now emerging that (i) enhance the quality of soil surveys and the efficiency with which they are made, and (ii) improve their interpretation for agricultural uses.

Some of the state-of-the-art soil survey techniques—the use of video image analysis, ground-penetrating radar, spatial databases—have recently been reported in *Soil Survey Techniques*, SSSA Spec. Publ. 20 (Reybold & Peterson, 1987). Apart from advances in remote sensing, the development of a computer technology known as geographic information systems (GIS) has been especially important. GIS code, store, retrieve, transform, and display maps of land attributes, such as geology, terrain, climate, and vegetation. GIS also have relational database capabilities and thus can manipulate data to create new maps and data elements. Inasmuch as soil variability is predictable to the extent that the factors of soil formation and their influence on pedogenic processes are known, computer programs could be developed that use this information to predict what kind of soil is likely to be found at a specific location.

Computer-aided technologies that can be employed successfully to improve land evaluation include, in addition to GIS, relational databases, crop simulation models, stochastic weather generators, strategy analysis software, pest and pest-loss models, erosion models, farming systems models, and expert systems for various knowledge domains. These techniques can be used to refine yield predictions, evaluate land use alternatives, assess the long-term environmental consequences of agricultural practices, and formulate

national and regional production plans. Although at this time, the new technologies are best suited for land evaluation at macroscales where qualitative or semiquantitative assessments suffice, they have nevertheless helped to transform the complex process of land evaluation from an art to a science.

As the degree of sophistication of data management, models, and expert systems increase, so does the amount and specificity of the data required to drive the software. For many areas of the tropics, however, the information is either incomplete or lacking. Burrough (1988) has termed this state of affairs the "parameter crisis"—too many models chasing too few data. There are basically three solutions to this predicament, none of them easy:

1. Collect more data in traditional ways.
2. Make better use of existing data.
3. Generate data with innovative techniques.

The estimation of soil properties, in the absence of site-specific data, appears to be a problem indeed. Yet, assuming that a profile description for the site is available, one could combine certain parameters from this description (horizon depth and thickness, color, texture, and structure) with chemical, physical, and mineralogical properties estimated from characterization data for soils belonging to the same taxon and construct a "synthetic pedon." If the U.S. system of soil taxonomy classification of the soil is not known, an expert system approach can be employed to arrive at an approximation.

But even where soil surveys and characterization data are available, there still is the problem of spatial and temporal soil variability that is particularly important if the new technologies are to be applied at the farm level. In the tropics, it is not unusual that more than one-half of a mapping unit of detailed soils surveys is composed of soils that differ in varying degrees from the typifying soil series. Running a crop model with data derived from the typifying series, may therefore produce quite erroneous results. This dilemma can be solved, however, with a simple expert system. As the range of soils that may conceivably be included in a specific mapping unit of a given area is limited, a pedologist familiar with the area can, by asking a few key questions that a layperson can answer, determine with considerable accuracy what kind of soil occurs at a particular point of a mapping unit.

The emergence of a multitude of agricultural and environmental models that require quantitative soil data has markedly increased the demand for this information in recent years. Soil surveys are the primary source of this information. But as the soil properties routinely determined in soil surveys are not necessarily those required by the models, soil scientists are confronted with the task of developing default procedures to derive the needed parameters from the existing data. Also, it is likely that feedback from the new group of users will impact on the way soil surveys are conducted in the future, particularly with regard to the description and characterization of the tillage zone of the soil.

The application of advanced technologies to deal with the diversity of tropical soils in a development context offers many opportunities but is frequently hampered by the scarcity of site-specific information. The critical

need for soil information not only reaffirms the necessity and value of soil survey, but also challenges pedologists to innovatively generate surrogate information to cope with the cases where the pressure for development precludes the generation of resource information with conventional methods.

## CONCLUSIONS

As recently as 1972, the prestigious Economic Development Institute of the International Bank for Reconstruction and Development published a treatise that contains the following statement:

Over a very large part of the humid tropics, the soil has become laterite. That is, through leaching of the main plant foods, the assimilable bases and phosphorus, are removed from the top horizons of the earth. What is left is a red-dish mottled clay, consisting almost entirely of hydroxides of iron and alumina whose most distinctive trait is the tendency to solidify on exposure to air . . . The pure laterites and latosols cover the greater part of the humid tropics and are either agriculturally poor or virtually useless (Karmarck, 1972).

Although clearly a myth, notions of this nature continue to be perpetuated even today. Yet, soils that conform to this description—Oxisols and Ultisols, with plinthite—occupy a very small portion of the tropics, perhaps not more than 2%. In fact and as elaborated above, soil diversity in the geographic tropics is at least as large as that of the temperate zone. This is, of course, patently logical if one considers the enormous variability in the environmental factors that control soil formation in the tropics. Covariant with the taxonomic diversity is a wide range of physical, chemical, and mineralogical properties and resultant soil fertility and production potentials.

No less an authority than Charles E. Kellogg (1967)

. . . fully expects that 'some day' the most productive agriculture of the world will be mostly in the tropics, especially in the humid parts. . . . Whether 'some day' is 25, 50, 100, or some other number of years from now, depends on how rapidly institutions for education, research, and the other public and private sectors of agriculture will develop.

Today, more than 20 yr after this statement was made, "some day" may have arrived at some plantations and a few other areas. For the most part of the tropics, however, some day remains a futuristic fantasy rather than a realistic scenario. Small-scale farming prevails in most of the region and, as Lal (1987) has pointed out,

the subsistence farmer who faces famine would consider a successful technology to be the one that produces some yield in the worst year rather than the one that produces a high yield in the best.

But efforts to improve the productivity of subsistence farming are just beginning to get the attention of the national and international agricultural research centers. Emerging technologies such as agroforestry, alley and multiple cropping, improved genetic material,  $N_2$ -fixing trees and crops, and biotechnology hold much promise. In the context of this chapter it should also be mentioned that it would be advantageous if the new farming systems de-

veloped are robust enough to be insensitive to the field-scale soil microvariability that tends to exist on tropical farms.

As the world will eventually have to feed 10 billion people, much of the as yet underutilized land in the tropics will have to be brought under cultivation. Can there be sustainable agriculture on these lands? The four basic causes of land degradation—overgrazing on rangeland, overcultivation of cropland, waterlogging and salinization of irrigated land, and deforestation—all result from poor land management and can, therefore, at least in principle, be controlled. The record to date, however, is quite poor. Although effective technologies that prevent or reduce land degradation either exist or are being developed (Postel, 1989), their application is still constrained by institutional and societal barriers. The problem is aggravated by the fact that degradation control crosses all traditional boundaries and that lasting solutions must be rooted as much in social and economic reform as in effective technologies (Postel, 1989). In the tropics, as elsewhere, the prospects for institutionalizing sustainable development strategies are not encouraging.

## REFERENCES

- Birkeland, P.W. 1984. Soils and geomorphology. Oxford Univ. Press, New York.
- Burrough, P.A. 1988. Modelling land qualities in space and time: The role of geographical information systems. p. 91–105. *In* Invited papers presented at the Symp. on Land Qualities in Space and Time, Wageningen, Netherlands. 22–26 Aug. Agric. Univ. Wageningen, Wageningen, Netherlands.
- Dudal, R., and H. Eswaran. 1988. Distribution, properties and classification of Vertisols. p. 1–22. *In* L.P. Wilding, and R. Puentes (ed.) Vertisols: Their distribution, properties, classification and management. Publ. Soil Manage. Support Serv., Washington DC.
- Kamarck, A.M. 1972. Climate and economic development. EDI Seminar Paper no. 2. Economic Development Inst., Int. Bank for Reconstruction and Development, Washington, DC.
- Kellogg, C.E. 1967. Comment. p. 232–233. *In* H.M. Southworth and B.F. Johnston (ed.) Agricultural development and economic growth. Cornell Univ. Press, Ithaca, NY.
- Lal, R. 1987. Managing the soils of sub-Saharan Africa. *Science* 236:1069–1076.
- Little, P.D., and M.H. Harowitz. 1987. Social science perspectives on land ecology and development. p. 1–3. *In* P.D. Little et al. (ed.) Lands at risk in the third world: Local level perspectives. Westview Press, Boulder, CO.
- Postel, S. 1989. Halting land degradation. p. 21–40. *In* L.R. Brown (ed.) State of the world 1989. A Worldwatch Institute report on progress toward a sustainable society. W.W. Norton and Co., New York.
- Reybold, W.U., and G.W. Peterson (ed.). 1987. Soil survey techniques. SSSA Spec. Publ. 20. SSSA, Madison, WI.
- Soil Survey Staff. 1975. Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. USDA-SCS Handb. 436. U.S. Gov. Print. Office, Washington, DC.
- Virmani, S.M., and H. Eswaran. 1991. Concepts for sustainability of improved farming systems in the semi-arid regions of developing countries. Int. Conf. "Soil Quality in semi-arid agriculture," Saskatoon, Canada. (In press.)
- Yost, D., and H. Eswaran. 1991. Major land resource areas of Uganda. (In press.)